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# Multi-taxa inventory of naturalized species in Chile

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## Abstract

Here we present a multi-taxa inventory of naturalized alien species recorded on continental Chile and adjacent marine habitats, including eight taxonomic groups. We identified 1,122 species. These comprise 790 vascular plants (terrestrial and aquatic); 31 nonvascular plants [Bryophyta (mosses), Marchantiophyta (liverworts) and Anthocerotophyta (hornworts)]; 18 marine and freshwater macro and micro algae; 71 fungi; 39 terrestrial vertebrates (amphibians, reptiles, mammals and birds); 108 insects; 37 marine and freshwater invertebrates and vertebrates (6 polychaetes, 3 mollusks and 28 Pisces); and 28 terrestrial gastropods. For all taxonomic groups, naturalized species were found to mainly be distributed in regions with Mediterranean and temperate climates, with few at either extreme of the country. The invasion curves show that naturalized species first underwent a positive increment, followed by an apparent plateau phase,

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mainly in vascular plants, insects and vertebrates. In fungi, marine and freshwater macro and microalgae, vertebrates and invertebrates, the cumulative number of naturalized species increased sharply starting in the early 20th century; the lack of collections before 1900 is also evident. When considering naturalized species as a whole, this inventory highlights that the rate of new naturalizations consistently increased after 1950, especially for some taxonomic groups such as insects, fungi, and vascular plants. This multi-taxa inventory of naturalized species provides a platform for national reporting on biodiversity indicators and highlights areas where Chile must invest resources to manage biological invasions.

**Keywords**
alien species, Chile, database, invasion periods, rate of introduction

## Introduction

Inventories of naturalized alien species are not only fundamental to elucidate the causes and consequences of the invasion phenomenon (Mack et al. 2000; Pimentel et al. 2005; van Kleunen et al. 2015; Seebens et al. 2017), but also because of their relevance in nature conservation, ecosystem functioning, human health and economy (Hulme 2009; Pyšek and Richardson 2010). Currently, there is an urgent need for inventories of naturalized species, since they reflect these species' local patterns and provide critical information about invasive species distribution (van Kleunen et al. 2015; Seebens et al. 2017). However, in developing countries, naturalized species distribution is still poorly documented and understood (Gardener et al. 2012; Speziale et al. 2012; but see Castilla et al. 2005; Moreno et al. 2006; Castilla and Neill 2009 for marine non-native species; Fuentes et al. 2013 for plants). These species have been neglected in collections and studies due to a historical bias that found no scientific value in studying the naturalized component (Pauchard et al. 2004; Fuentes et al. 2013). Thus, a national Chilean naturalized species inventory is now essential for the early detection and potential eradication or control of invasive species through risk assessment protocols (Moreno et al. 2006; Fuentes et al. 2010, 2013). Additionally, naturalized species inventories provide datasets suitable for the analysis of temporal patterns of biological invasions, in contrast with the current pattern that reflects geographical biases in information on invasion patterns (Pyšek et al. 2008; Núñez and Pauchard 2010).

Approaches such as invasion curves and variations in the rate of naturalized species introductions allow us to identify invasion periods as well as the temporal dynamics of species accumulations (Fuentes et al. 2008; Seebens et al. 2017). Pyšek and Prach (1993) prepared invasion curves methods for reconstructing the propagation history of four alien species in the Czech Republic. They adjusted an exponential model to the accumulated number of locations against time. The slope of the corresponding regression line was used as a measure of the invasion rate (Mihulka and Pyšek 2001). Abrupt inflexions on the invasion curve indicate expansion periods

of the alien species involved (Pyšek and Prach 1993). In this context, whether different taxa show similar invasion curves in a given region is an open question, hence, comparing invasion curves can reveal differences in the invasion process. Seebens et al. (2017) proposed that differences in the pathways and distribution of species introductions suggest that the chronology of invasion could vary among taxonomic groups. This approach allows us to infer whether the increase in numbers of naturalized species shows any sign of saturation, or whether we can expect biological invasions to continue increasing (Seebens et al. 2017).

A substantial part of Chile has been recognized as a hotspot of world biodiversity (Ormazabal 1993; Myers et al. 2000; Mittermeier et al. 2005) due to its remarkably high levels of endemism and the biogeographic isolation of several taxonomic groups (Armesto et al. 1998; Habit et al. 2006; Vidal and Díaz-Páez 2012; Rodríguez et al. 2018), raising concerns regarding its susceptibility to invasions (Arroyo et al. 2000; Fuentes et al. 2015; Seebens et al. 2017). The extraordinary biogeographic characteristics of Chile make it ideal for understanding biological invasion patterns and have great potential for inferring future invasion trends. However, the study of biological invasions in Chile has been addressed mainly in the last decade, both in terrestrial (Quiroz et al. 2009), and marine systems (Castilla and Neill 2009; Villaseñor-Parada et al. 2017). Therefore, the few inventories that exist of naturalized species have been created for only certain taxonomic groups (e.g., boring polychaetes, Moreno et al. 2006; vascular plants, Fuentes et al. 2013; ascidians, Turon et al. 2016; aquatic plants, Urrutia et al. 2017; marine seaweed, Villaseñor-Parada et al. 2018), with no comprehensive inventory of naturalized species, which would allow for the identification of invasion patterns at the multi-taxa level. To address this knowledge gap, the Project GEF/MMA/PNUD, aimed to develop the first national inventory of naturalized species, including eight taxonomic groups recorded on continental Chile and adjacent marine habitats (PNUD 2017). In this paper, we have updated these lists with current taxonomic status and the full dataset has been included as supplementary material. Here, we present a comprehensive inventory of naturalized species in Chile and analyze the distributional and temporal trends of biological invasions in the country in order to identify priority responses to the growing threat from biological invasions.

## Methods

Continental Chile extends over 38.5 degrees of latitude (17.5°–56°S; 4300 km), and administratively, the country is divided into 16 regions (which range from 15,403 to 132,291 $km^2$ in size) and 56 provinces, sequentially ordered from north to south. This arrangement is closely correlated with increasing precipitation and decreasing temperatures with increasing latitude (di Castri and Hajek 1976; Luebert and Pliscoff 2006). This establishes a smooth gradient in climatic conditions

and a sequence of biomes, from hyperdesert in the north, a Mediterranean climate region in the center and temperate rain forest and cold sub-Antarctic wetlands in the south. In this physical pattern, most of the human population, which is associated with greater environmental alterations, is distributed mainly in the Mediterranean area. In relation to marine systems, the oceanographic conditions of the Chilean coast are strongly influenced by the Humboldt Current System and the Cape Horn Current (Camus 2001; Thiel et al. 2007). To the north of 42°S, the Chilean coast is virtually a line, with few geographical features, but strongly influenced by diverse factors, such as upwelling and El Niño Southern Oscillation (ENSO). On the contrary, south of 42°S is characterized by the high occurrence of geographical accidents, and low salinities due to the influence of fjords (Camus 2001, 2008; Thiel et al. 2007).

We performed an exhaustive bibliographic revision and used herbarium and zoological collections to identify all the species recorded as naturalized in continental Chile and adjacent marine habitats for each of the eight taxonomic groups: a) vascular plants (terrestrial and aquatic); b) nonvascular plants [Bryophyta (mosses), Marchantiophyta (liverworts), and Anthocerotophyta (hornworts)]; c) marine and freshwater macro and micro algae; d) fungi; e) terrestrial vertebrate fauna (amphibians, reptiles, birds and mammals); f) insects; g) marine and freshwater vertebrates (Pisces) and invertebrates (polychaetes and mollusks); and h) terrestrial gastropods. For each taxonomic group, we used the most accepted and comprehensive definition of naturalized species (see Table 1 for details). In general terms, naturalized species were considered as those that are not native to Chile (i.e. nonindigenous) and whose presence is due to intentional or accidental introduction as a result of human activities. We considered all organisms that are naturalized or invasive, but not those that survive only with human assistance (Richardson et al. 2000). The preliminary list of each taxonomic group was then verified by experts (local and international). Thus, we had a second opinion regarding the inclusion or rejection of naturalized species in the database. For each species, we made a substantial effort to compile and organize a database integrating both species characteristics and spatial distribution information (see Table 2 for details). We checked all records for their scientific names and spatial distributions.

To construct the invasion curves of naturalized species we modified the procedure in Pyšek and Prach (1993), following Fuentes et al. (2008). We plotted the cumulative number of species collected/recorded in Chile against time in 20-year periods. Data on the first-year records were gathered from various sources (including online databases, scientific peer-reviewed publications, reports and books) and analyzed for 20-year periods. For invasion curves and the annual rate of first records, we only included species that were first reported in a known year. Thus, terrestrial gastropods, as well as marine and freshwater vertebrates, were excluded from these analyses.

**Table 1.** Definitions of naturalized alien species for each taxonomic group included in the inventory.

| Taxonomic group | Definition |
|---|---|
| Naturalized vascular plants (terrestrial and aquatic) | We included all naturalized alien species *sensu* Richardson et al. (2000). Additionally, we used expert criteria when the status of the plant species was ambiguous or not supported by publications. Due to a lack of knowledge regarding the native ranges of several species in southern South America (i.e. among Chile, Argentina, Perú, and Bolivia) and to avoid problems in relation to their status (i.e. naturalized or native), we deliberately excluded plants whose natural distribution range fell within the neighboring regions and shared an immediate border with Chile. For this group, the database was constructed on the most recent research by Fuentes et al. (2013), and updated to include new records and spatial information. |
| Naturalized nonvascular plants (Bryophyta (mosses), Marchantiophyta (liverworts) and Anthocerotophyta (hornworts)) | To classify naturalized species in this group we utilized six criteria following Crundwell (1985): 1) absence of subfossil record, 2) evidence of a change in geographical distribution, 3) anomalous geographical distribution, on a world scale or locally, 4) association with some means of introduction e.g. botanic garden or ports, 5) less than the normal amount of genetic variation in populations. Sometimes in dioecious species only one sex is present, and 6) association with open, disturbed or temporary habitats. |
| Naturalized marine and freshwater macro and microalgae | For both marine and freshwater environment, we included all naturalized species referring to organisms that have established a self-sustaining population, but have not necessarily been involved in an invasion process (Richardson et al. 2000; Falk-Petersen et al. 2006). We considered 12 criteria proposed by different authors to identify species introduced into marine systems worldwide (Chapman and Carlton 1991; Cranfield et al. 1998; Ribera and Boudouresque 1995; Boudouresque and Verlaque 2002), and these were: 1) new report in one area, 2) geographical discontinuity in its worldwide distribution, 3) expansion of its distribution range in the invaded area from its point of introduction following a logical pattern (e.g. gradual decrease in abundance from its point of introduction, colonization of new sites following a spatio-temporal pattern), 4) very localized distribution in the introduced region, restricted when compared with similar native species (for example, of the same genus, of the same functional group, with similar life histories), 5) proximity to the probable source of introduction (e.g. ports, cultivation centers), 6) association (or dependence) with other introduced species, 7 ) association (or dependence) with anthropic activities (e.g. colonizes docks or other artificial substrates), 8) no native evolutionary origin (e.g. absence of congeners in the variable range), 9) tendency to generate massive proliferations (at least seasonally), 10) is identified as naturalized or invasive in other parts of the world, 11) life stories that infer a high invasive power, and 12) genetically identical distant populations. |
| Naturalized fungi | For this group, the concept of naturalized species is not easily handled due to the lack of larger inventories of Chilean fungi before 1945. Also, the deficient knowledge in terms of the biogeography of fungi can make it difficult to determine what is a naturalized species. Priority was given to published records of biotrophic and saprotrophic specialists associated to allochthonous plants (trees), apart from collection specimens (CONC-F, Universidad de Concepción) recorded between 2004 and 2017 for the first time in Chile. The preliminary list was revised and completed by external experts. |
| Naturalized terrestrial vertebrates (mammals, birds, amphibians and reptiles) | In this taxonomic group, we included all naturalized species based on the definition proposed by the United Nations Development Program (UNDP). This definition includes all naturalized alien species that were introduced intentionally or accidentally by humans, establishing a self-sustaining population, without intervention by humans. This general definition was complemented by specific literature for this taxonomic group (e.g. Daniels and Corbett 2003; Lever 1994). |
| Naturalized insects | For this group, we included all naturalized alien species, referring to organisms that have established a self-sustaining population, but not necessarily ended up in an invasion process (Falk-Petersen et al. 2006; Carvallo 2009). |
| Naturalized marine and freshwater vertebrates and invertebrates (polychaetes and mollusks) and terrestrial gastropoda | We used the criteria proposed by Orensanz et al. (2002), Castilla et al. (2005) and Castilla and Neill (2009), which states the following: 1) status determined by scientific literature or expert criteria, 2) anomalous geographical distribution, on a world scale or locally, 3) species with wide geographic distribution, including cosmopolitan species, 4) species described as nonindigenous in Chile, and 5) species that are abundant near to ports or aquaculture centers, but rare or not present in other areas of the country. |

**Table 2.** Species traits, descriptions, and traits level included in the inventory of naturalized species present in Chile.

| | Plant traits | Description |
|---|---|---|
| **Taxonomic information** | Family, genus, scientific name and author | Text |
| **Distribution** | Native range | Name of the countries, continents or bioclimatic zones |
| | Administrative Regions occupied by the naturalized species in Chile | 15= AYP, Arica y Parinacota 1= TAR, Tarapacá 2= ANT, Antofagasta 3= ATA, Atacama 4= COQ, Coquimbo 5= VAL, Valparaíso 13= RME, Región Metropolitana 6= LBO, Libertador Bernardo O´Higgins 7= MAU, Maule 8= BIO, Biobío 9= ARA, La Araucanía 14= LRI, Los Ríos 10= LLA, Los Lagos 11 AIS, Aisén 12= MAG, Magallanes ND = no data. |
| **Introduction** | First year report | The year (or range) of the first report in Chile |
| | Type of introduction | Accidental / Intentional / Other |
| **Impacts** | Description of impacts | The known impacts produced by the species around the world. |

## Results

We identified 1,122 species, which we consider as naturalized at least in some parts of continental Chile and adjacent marine habitats (Table 3). These comprise 790 vascular plants (terrestrial and aquatic); 31 nonvascular plants (Bryophyta, Marchantiophyta and Anthocerotophyta); 18 marine and freshwater macro and micro algae; 71 fungi; 39 terrestrial vertebrates (amphibians, reptiles, birds and mammals); 108 insects; 37 marine and freshwater vertebrates and invertebrates (6 polychaetes, 3 mollusks and 28 Pisces); and 28 terrestrial gastropods (Table 3). For most taxonomic groups, the highest numbers of naturalized species were found mainly in the Mediterranean and rainy climatic zones (Table 3, Fig. 1A, B). Terrestrial vertebrates also showed a significant number of species in the cold steppe zone (Table 3), as did insects, and vascular plants in the semi-arid zone (Table 3, Fig. 1A, B).

The cumulative number of naturalized species collected in Chile over time (i.e. invasion curves) has shown a consistent increment in all taxonomic groups during the 19$^{th}$ and 20$^{th}$ century (Fig. 2). Despite the temporal differences among taxonomic groups in their first records, slopes of invasion curves for naturalized species did differ among taxonomic groups, suggesting different rates of species accumulations. While vascular plants, nonvascular plants, and terrestrial vertebrates showed a slight, but steady increase in the number of naturalized species over the last 150 years (Fig. 2A, B, F), the cumulative number of naturalized species in the remaining four taxa increased steeply at the beginning of the 20$^{th}$ century (Fig. 2C, D, E, G). The total rate of first records remained low between 1850 and 1950 (on average 2.8 first records annually, Fig 3A). Since 1951, first records have increased steeply (on average 5.9 first records annually, Fig 3A). During this period, the continuous increment in first record rates has been consistent in vascular plants, insects and fungi (Fig. 3B). On the contrary, nonvascular plants, terrestrial vertebrates, algae, and marine invertebrates have shown markedly low first record rates over the last 160 years (less than 1 first record annually, Fig. 3B).

**Table 3.** Number of naturalized species by climatic zones in continental Chile and adjacent marine habitats. The total number of species within each taxonomic group is given in parentheses. Marine organisms are present in the coastal area in front of each climatic zones.

| Climatic zones | Vascular plants (790) | Non-vascular plants (31) | Marine & freshwater macro- & microalgae (18) | Fungi (71) | Terrestrial vertebrates (39) | Insects (108) | Marine & freshwater vertebrates & invertebr. (37) | Terrestrial gastropods (28) |
|---|---|---|---|---|---|---|---|---|
| Desert | 192 | 0 | 4 | 1 | 13 | 38 | 6 | 1 |
| Semi-arid | 318 | 8 | 5 | 1 | 15 | 61 | 10 | 6 |
| Mediterranean | 636 | 29 | 11 | 55 | 31 | 108 | 25 | 9 |
| Temperate rainy | 463 | 14 | 13 | 41 | 20 | 78 | 12 | 10 |
| Cold steppe | 255 | 8 | 6 | 1 | 23 | 24 | 14 | 2 |

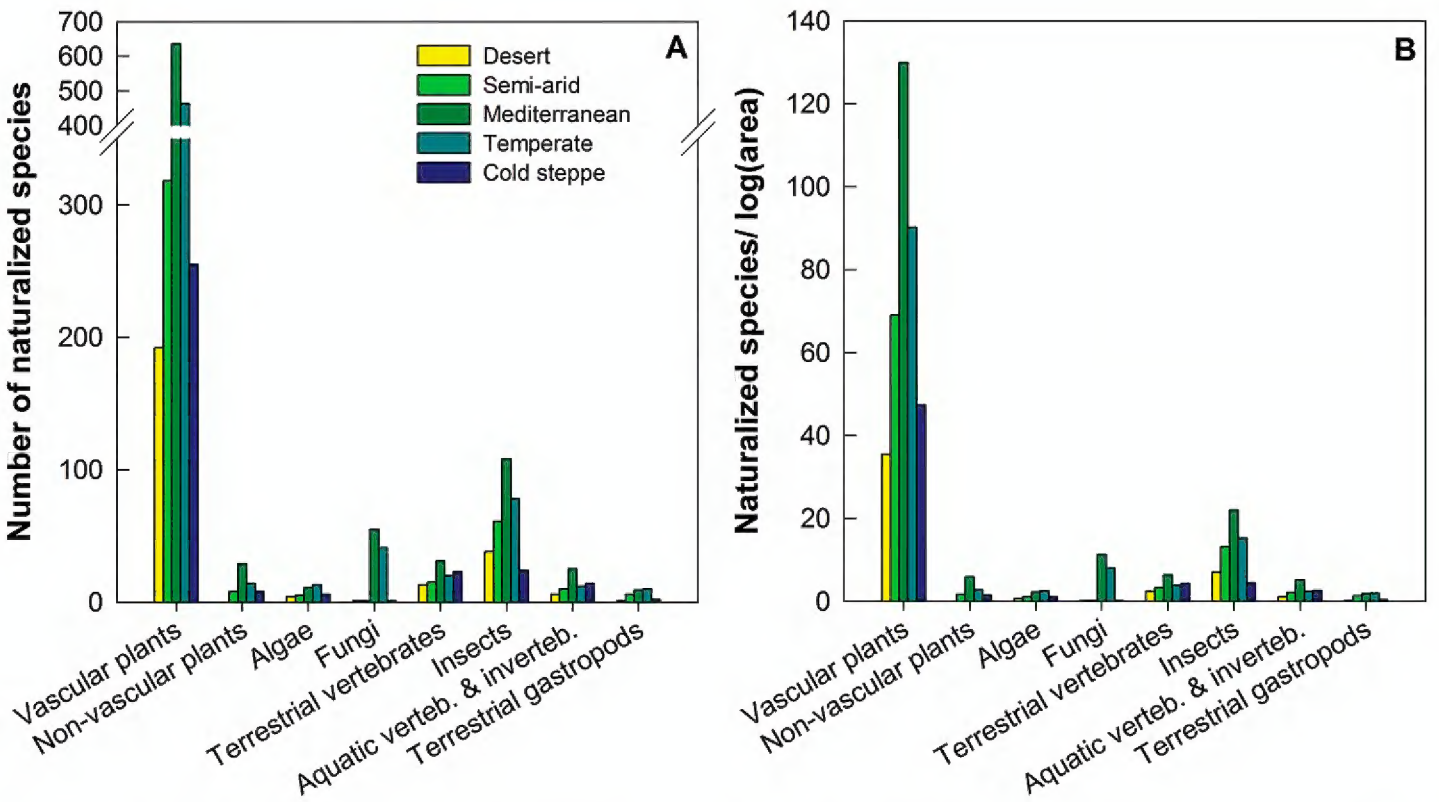


**Figure 1.** Total number of naturalized species (**A**) and number of naturalized species per log(area) (**B**) by climatic zones of continental Chile and adjacent marine habitats.

## Discussion

Unlike previous studies that have provided a database of naturalized species in Chile (e.g., Fuentes et al. 2013 vascular plants; Moreno et al. 2006 boring polychaetes; Turon et al. 2016 ascidians; Urrutia et al. 2017 aquatic plants, Villaseñor-Parada et al. 2018 marine seaweed and Castilla et al. 2005; Moreno et al. 2006; Castilla and Neill 2009 for marine non-native species), here, we present the first multi-taxa dataset of naturalized species for the whole country. Unfortunately, there are biases in creating this type of inventory because vascular plants are over-represented compared to other taxa, probably because they are more conspicuous, stationary and hence more easily discovered (DAISIE 2009). This plant bias occurred in the present study, where 74.1 % of

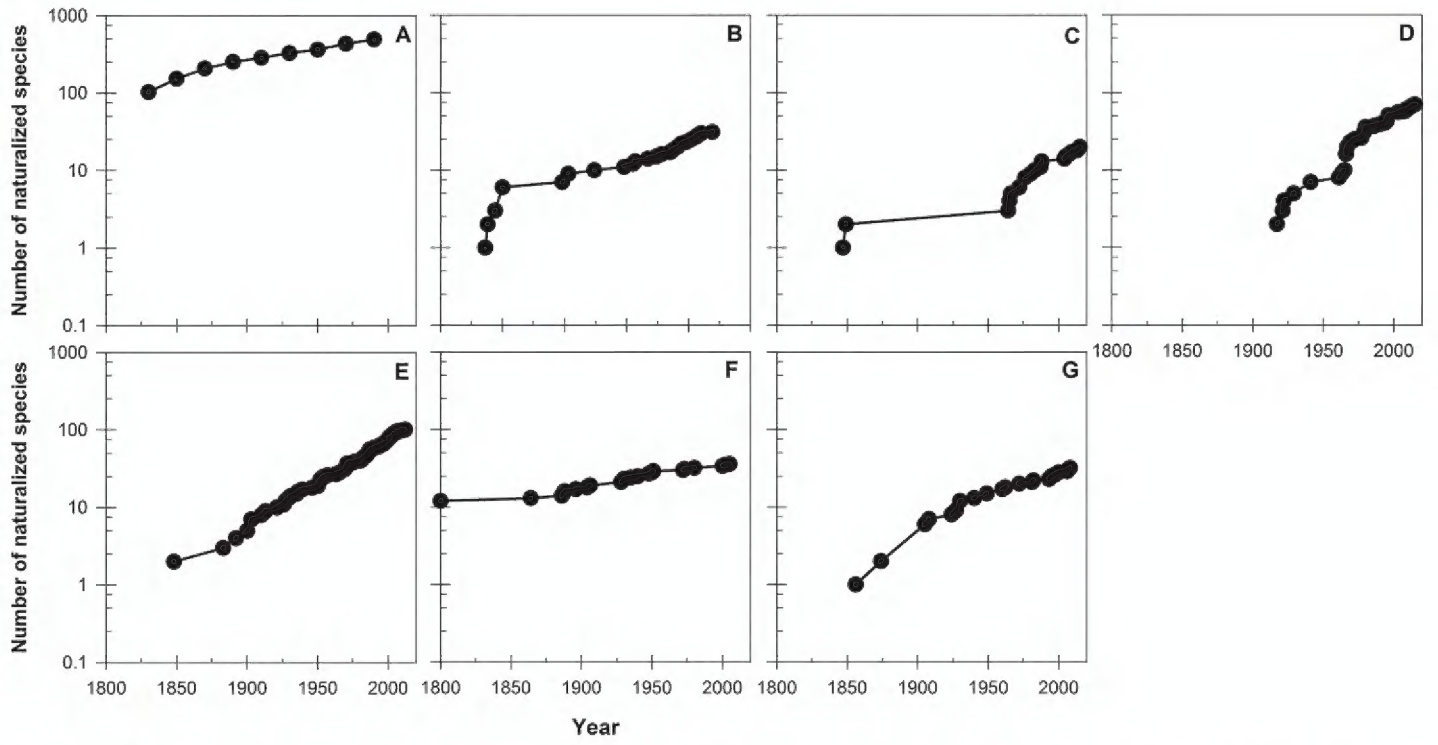


**Figure 2.** Temporal trends in the invasion of naturalized species in continental Chile and adjacent marine habitats, for each taxonomic group for which data on introduction dates were available (terrestrial gastropods are not shown due to lack of data). The cumulative number of recorded species is shown over the last 200 years. **A** vascular plants **B** nonvascular plants **C** marine and freshwater macro and micro algae **D** fungi **E** insects **F** terrestrial vertebrate fauna and **G** marine and freshwater vertebrates and invertebrates.

the naturalized species recorded in Chile are vascular plants. Most of the naturalized species in this database came from herbarium records and zoological collections, while few came from literature. Regarding fauna, there were also some biases in the data sources, e.g. while vertebrates were well represented in museum collections, records of naturalized insects came mainly from literature. The use of natural history collections as the primary source of information highlights their role in naturalized species studies at large spatial and temporal scales in Chile (e.g. see Fuentes et al. 2015 for vascular plants). The present study integrates data in a unique inventory to obtain a more realistic pattern of naturalized species richness and distributions. One major issue came up; when the number of records for certain naturalized species was still particularly low, we could not be completely certain whether these species had naturalized in the area (e.g., nonvascular plants which were poorly sampled before 1950). Nonetheless, the more than 1,100 well-checked species reported in this study should be sufficient to diagnose the situation in Chile in the past and evaluate future risks.

For all taxonomic groups, naturalized species were found to be mainly distributed in Mediterranean and temperate climate regions (central and central-southern Chile), with few species recorded in the far north and south of the country. In the case of vascular plants, several authors have shown similar distribution patterns for naturalized species (Castro et al. 2005; Fuentes et al. 2008; Fuentes et al. 2013). The high concentration of naturalized species in these two climate zones can be related to the fact that since Spanish colonization, most Chileans have lived in this area (ca. 80 % of the population) (Fuentes et al. 2013). Consequently, this area has been strongly trans-

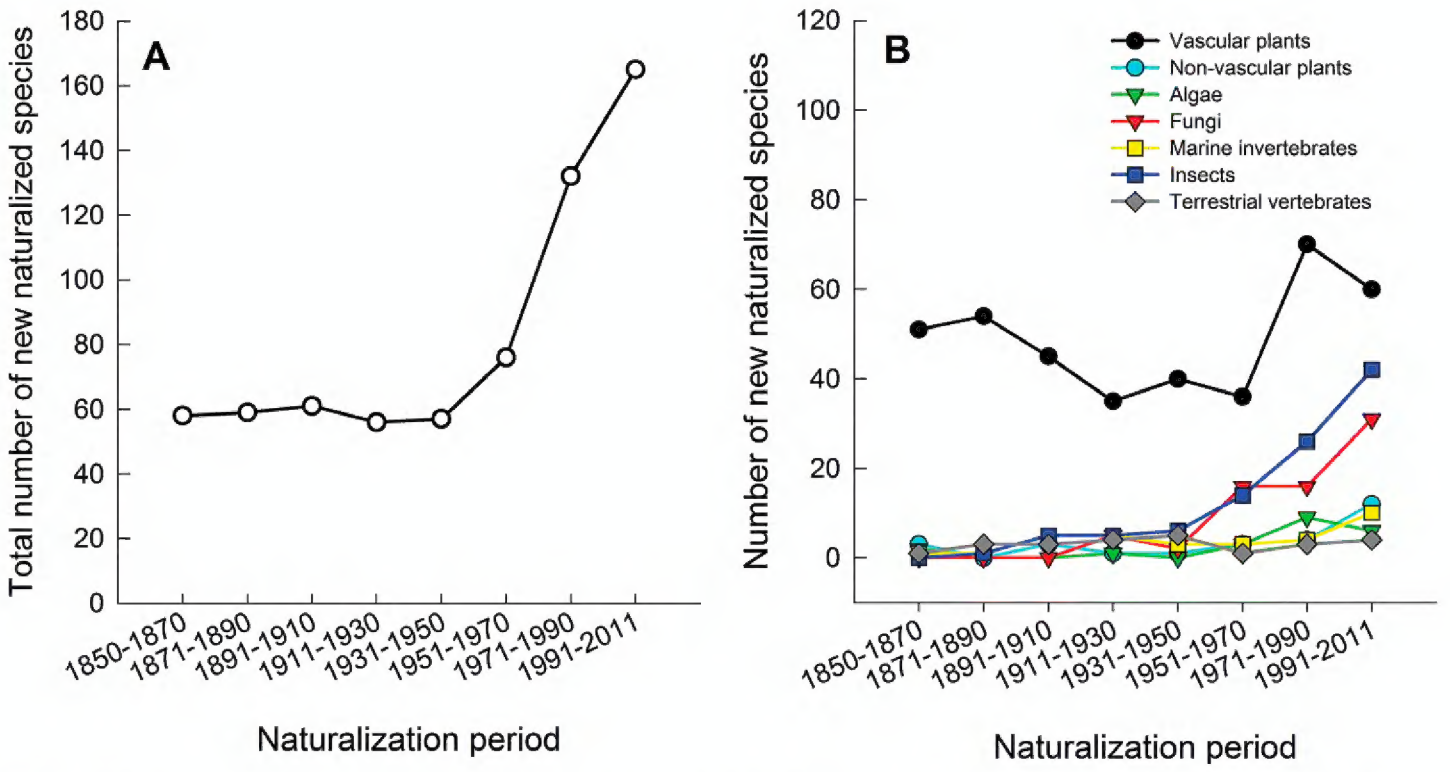


**Figure 3.** Total temporal trends in first record rates for all species (**A**) and seven taxonomic groups (**B**) in Chile. Terrestrial gastropods, as well as marine and freshwater vertebrates are not shown due lack of data.

formed by human activities and land-use changes, while the northern and southern areas have been relatively isolated, mainly due to their climatic conditions and remoteness from the main cities in central-southern Chile (Arroyo et al. 2000; Fuentes et al. 2008, 2015). In marine systems, ship traffic, ballast water and activities associated with aquaculture have been identified as the main introduction vectors for naturalized species (Naylor et al. 2001; Hewitt et al. 2009). In Chile, the main ports are located on the south-central coast (e.g. Valparaíso 33°S, San Antonio 33°35'S, Lirquén 36°42'S, Talcahuano 36°43'S, San Vicente 36°44'S, Coronel 37°01'S and Corral 39°52'S), which increases the susceptibility of these ecosystems to be invaded by naturalized species. Paradoxically, this sector of the Chilean coast has been one of the least studied in terms of biological invasions (Villaseñor-Parada et al. 2017), and even though the number of reports of naturalized species was found to be high, this number could be underestimated due to the lack of information available (Camus 2005; Carlton 2009; Castilla and Neill 2009; Villaseñor-Parada et al. 2017). The few naturalized species recorded in the extreme north and south of the country, could be associated with sampling efforts in these areas, the fact that naturalized species have not yet arrived to these areas due to low propagule pressure or introduction effort, and/or the fact that some species may have arrived, but not thrived because such habitats were incompatible with their ecological niches (Garrido 1985; Jaksic 1998; Fuentes et al. 2015; Villaseñor-Parada et al. 2017, 2018). For vascular plants in particular, the low species density in the Atacama Desert may be attributable to the harsh climatic conditions there, while the lack of naturalized plants in the far south may be the result of a combination of inaccessibility and lower levels of anthropization (Fuentes et al. 2008, 2015). In the case of insects, the highest presence of naturalized species was found to be concentrated in

Chile's central zone, which could be explained by the higher concentration of seaports, border crossings and airports, and the import of biological control agents (Parra and González 2007), pollinators (Montalva et al. 2008), and products of plant or animal origin that, in turn, are contaminated with foreign insects (Estay 2016). Thus, a more comprehensive inventory of naturalized species in these areas will help to identify priority responses to the growing threats from biological invasions.

Thorough documentation of the accumulation of naturalized species, allows us to assess the accumulation process and the dynamics of the establishment and expansion of naturalized species in Chile. We identified invasion periods in Chile based on bibliographic revisions, herbarium and zoological collections for each of the eight taxonomic groups analyzed. Comparatively, the invasion curves show that naturalized species first underwent a positive increment, followed by an apparent plateau phase, mainly in vascular plants, nonvascular plants, and terrestrial vertebrates. In the remaining four taxonomic groups (fungi, insects, marine and freshwater vertebrates and invertebrates, macro and microalgae), the cumulative number of naturalized species increased abruptly at the beginning of the 20$^{th}$ century. The lack of collections before 1900 is also evident for most of the taxonomic groups. In marine systems, the first reports of marine flora and fauna date back to the end of the 18$^{th}$ century, as a result of scientific expeditions that were limited to enumerating the different taxa collected, with few and brief descriptions (Etcheverry 1958; Ramírez 2010). In 1940, the first publications by resident Chilean taxonomists who ratified and added information on the presence of the aforementioned taxa started to appear (Ramírez 2010). Therefore, although the results observed when analyzing the temporal trend of marine invasions show a growing increase since 1900 (Fig. 2C, G), these results are biased due to a lack of prior information before this date. Since the Spanish colonization, an important number of species has been introduced in the drier central Mediterranean climate area, associated with landscape transformations (Aronson et al. 1998). Additionally, in the 19$^{th}$ century there was an important increase in the number of biodiversity records in Chile associated with the inventories developed by naturalists, such as Claudio Gay (Gay 1845, 1854). For vascular plants, there were sustained increments in the collection of weeds from 1894 to 1934, associated with wheat imports (Matthei 1995), whereas the increase of naturalized fungal species, especially macromycetes, is strongly correlated with the fast and extensive spread of naturalized timber plantations, mainly pine and eucalyptus, during the late decades of the 20$^{th}$ century (Palfner and Casanova 2019). The latter authors observed an almost threefold increase in allochthonous, and ubiquitous fungi associated with *Pinus radiata* plantations in central-southern Chile within the last 40 years. For other taxonomic groups, such as terrestrial vertebrates, the record of introduced species is relatively more complete and the relative lower rate of increase may be due to control measures implemented by government services (Iriarte et al. 2005). Specific phytosanitary regulations and other laws related to the introduction of naturalized species have most likely worked in these cases.

Considering naturalized species as a whole, this inventory highlights the consistent increase in the rate of new naturalizations since 1950, especially for some taxonomic groups, such as insects, fungi, and vascular plants. Even where rates of establishment

did not prove to be rising for nonvascular plants, algae, marine, and terrestrial vertebrates, the cumulative number of naturalized taxa did show a consistent increase for these taxonomic groups. Our results are consistent with the fact that the annual rate of first records worldwide has increased during the last 200 years, with 37% of all first records reported recently (1970–2014) (Seebens et al. 2017). Continuous increases in the rates of naturalized species first records in Chile, stress the need to improve the implementation of national legislation and international agreements that aim to reduce the threats that naturalized alien species pose to biodiversity, particularly in the case of insects and fungi. Additionally, the above pattern suggests that the number of new naturalized species will most likely continue to increase because current tools to prevent biological invasions are not effective enough to slow down the increment in the number of naturalized species (Seebens et al. 2017). This inventory is a basis for future studies that analyze more detailed biological patterns and mechanisms that explain invasion processes in many taxa that have been understudied (*sensu*, Capdevila-Argüelles and Zilletti 2005). In this context, to effectively assess consequences and risks, in terms of the spread and invasion of individual species, documentation with an efficient combination of species records requires a coordinated effort across multiple government agencies and research institutions, in addition to well-designed and specifically oriented sampling and monitoring programs.

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## Supplementary material 1

**A comprehensive inventory of naturalized species in Chile**

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